Department of Science and Agriculture

BARBADOS

AGRICULTURAL JOURNAL

Vol. 3, No. 3. **July, 1934.**

Advocate Co., Ltd.,—Printers & Bookbinders to the Government of Barbados.

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The Coral Limestone Soils of Barbados

S. J. SAINT, M.Sc., Ph.D. F.I.C.

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INTRODUCTION.

The Coral Limestone formation of Barbados covers about six-sevenths of the entire area of the Island and was formed, according to the most generally accepted opinion, in Pleistocene times. There are two theories to account for the formation and subsequent elevation of the coral limestone. Harrison and Jukes Brown (1) consider that the coral was put down in a series of fringing reefs as the island rose, vertically, above the sea. Trechmann (2) has recently criticised this view. He advances evidence which appears to prove that practically all of the coral rock covering was formed before the uplift commenced. He further shows that this uplift was not directly vertical, but was an oblique or differential one and that the terraces are due to fault scarps assisted by wave action.

Whichever view is adopted, it is quite certain that the coral rock at the highest elevation became dry land in the first stages of the uplift and has therefore been exposed for a longer period to the action of atmospheric weathering agents. Hence the soils found on the highest part of the island should be of greater age than those found below. It would appear then that a study of the high and low level soils should shed some light on the accumulated effect of weathering agents on the development of soil from the coral limestone. This aspect will be dealt with later.

The soil overlying the coral limestone is, for the most part, of limited depth and does not often exceed 3—4 feet. Owing to the unevenness of the coral rock, however, the soil may vary in depth from several inches to several feet in the same field. Swallow holes are often met with in the coral rock and the filling up of these results in depths of 50 feet of soil or more in some places.

It will be seen, on reference to the map, that in the south part of the island, there is a ridge rising to about 400 feet, running nearly east and west—the Christ Church dome—and a broad valley—the St. George's Valley—between this elevation and the main part of the island. Deep soils are generally met with in the St. George's Valley and these are apparently due to the washing down of soil from the higher slopes. Trechmann considers that the elevation of the Christ Church dome was formed subsequently to that of the main part of the island by a thrust from the south. As will be shown later, the stage of development of the soils on this ridge supports this view.

The soils overlying the coral rock have apparently been formed from the weathering of the limestone with the addition of volcanic dust which has fallen on the island from time to time as the result of volcanic eruptions to the westward. The last falls of dust were in 1902–3 and the particulars set out in Table I, which were recorded at the time, are taken from the files at the Government Laboratory. The silica-alumina ratios of these volcanic dusts are of the same order of magnitude as those of the latest formed or black soils of the coral limestone.

TABLE I.

Date of Fall of dust.	Rate of Fall per acre.	CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	SiO_2/Al_2O_3 (molec ratio).
7th May 1902	Not recorded.	10·0	4·7	21·6	6·4	51·5	4·02
16th Oct. 1902	3·9 tons	9·1	4·0	21·1	9·3	51·6	4·13
22nd March 1903	3·5 tons	10·1	5·9	12·6	14·1	50·7	6·80
Black Soil (Mean)				16·14	10·66	44·67	4·93

FACTORS AFFECTING SOIL DEVELOPMENT.

(1) SITUATION.

The Island of Barbados is pear-shaped with a maximum length of about twenty-one miles and a maximum width of about fourteen miles. It has a superficial area of approximately 166 square miles and is situated in latitude 13° 4′ north and longitude 59° 37′ west.

(2) RAINFALL.

The climate may be divided into two periods; the dry season which lasts from about December until May and the rainy season which covers the period from June until November. The driest months are from February until April and the wettest period is from August until November.

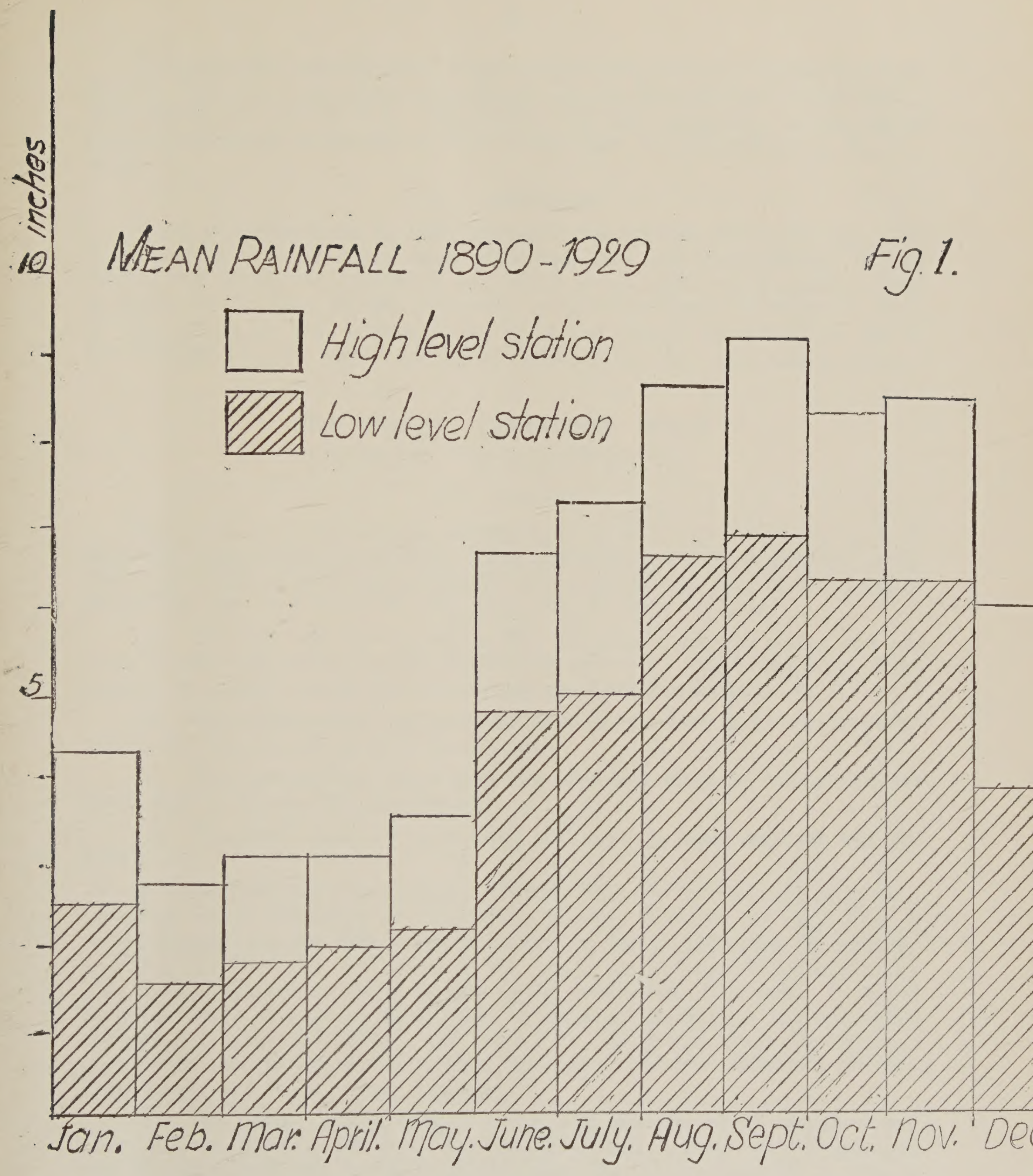
The average rainfall for the forty-year period 1889—1929 for the whole island is 60.9 inches, but the higher parts of the island invariably have a higher annual rainfall than those of lower elevation. Taking the average annual rainfall for the same forty-year period, it is found that the districts above 500 feet recorded 68.5 inches of rain, whilst the districts below 500 feet registered 53.4 inches. The average distribution for the years 1889—1929 is shown in Fig. 1.

During the dry season, the soils gradually dry out until, by the end of March, cracks are beginning to appear which, by the close of the dry season, may be large enough to take the leg of a horse. It is found that a good mulch of cane trash or grass, applied at the end of the rainy season, prevents this excessive drying out and the soil under the mulch remains damp well into the dry season and shows no signs of cracking.

(3) TEMPERATURE.

The shade temperature in Barbados averages about 79°F.; the diurnal fluctuations in temperature are relatively small.

From December until March the temperature may vary between 70°F. and 84°F.; these are the coolest months of the year. During the remainder of the year the normal temperature range is between 74°F. and 87°F.



MEAN RAINFALL 1890-1929
Fig. 1.
High level station
Low level station
10 inches
5
Jan.
Feb.
Mar.
April.
May.
June.
July.
Aug.
Sept.
Oct.
Nov.

The maximum and minimum extreme shade temperatures registered at Codrington (180 feet) and recorded by Skeete (3) for the nine-year period 1924—1933 are 91.5°F. and 63.0°F. Skeete states that the temperature in the highest parts of the island is usually 6—12°F. lower than the temperature in the lowlands.

(4) VEGETATION.

When first discovered in 1605, Barbados was covered with forest but, with the exception of a few acres, these conditions have long disappeared. It may be said that all the coral limestone soil, which is not built over, is planted either in sugar-cane, if deep enough, or in sour grass (*Andropogon pertusus*). Both of these plants are well adapted to the prevailing climate, since they are able to live through the dry season and grow rapidly when the rainy season sets in.

THE CORAL LIMESTONE SOILS.

PHYSICAL CHARACTERISTICS.

(1) COLOUR.

One of the most obvious and striking features of the coral limestone soils of Barbados is the difference in colour which exists between soils at different levels. The coral limestone soils can be classified into seven groups, four of which group themselves both on account of colour and altitude above sea-level.

(a) The *red soils* are usually a rich chocolate brown in colour and are found at altitudes above sea-level, of 700 feet and over. The brown tints of the surface red soils are partly due to the presence of organic matter.

(b) The *intermediate red soils* are browner in colour and occur approximately between the 400 and 700 feet levels.

(c) The *intermediate black soils* are brownish black in colour and are found mainly between 200 and 400 feet.

(d) The *black soils* are quite black and occur between sea-level and 200 feet.

In view of the fact that all these soils have been derived from the same coral limestone which, according to Trechmann, was put down at the same time, it would appear that the differences in colour are due to differences in maturity and that the black low level soils would, under natural conditions, eventually pass through the colour stages leading to the production of red soil. It should be noted that there are no sharp lines of demarcation between the red, intermediate red, intermediate black and black soils. They pass gradually from one type to the next as one descends from the high to the low levels and the altitudes chosen are, more or less, arbitrary.

(e) The *Christ Church Ridge* soils are also black in colour, but are found at an altitude of 200 to 400 feet. On grounds of colour, they would be grouped with the black soils and, as will be shown later, they are very similar in properties to the black soils. They would therefore be judged to be of somewhat similar age to the black soils and less mature than the intermediate black soils found on the main part of the island at a corresponding altitude. This conclusion is supported by the geological theory of uplift, advanced by Trechmann.

The other two soil types cover a relatively small area of Barbados; but since they are distinct in their field behaviour, they have been included in this soil survey.

(f) The *red sand soils* are found over a long narrow area on the leeward side of the island at an altitude of between 100 and 300 feet above sea-level. This soil type is reddish in colour and contains a relatively large proportion of quartz sand. It has been suggested that the quartz sand is derived from the Scotland deposits on the windward side of the island and were deposited by sea currents in their present position during that stage of the uplift of the island.

(g) The *St. George's Valley Soils* are found in the vale between the Christ Church dome and the main part of the island. They are deep soils with a stiff subsoil and tend to become water-logged in the wet season unless adequate field drains are made to carry off the excess water.

The comparative areas occupied by the red, black and red sand soils, if the intermediate red are included with the red soils and the intermediate black are included with the black soils, are as follows:—Red 32%, Black 65%, Red Sand 3%.

(2) MECHANICAL ANALYSIS.

The method adopted in these investigations has been the official pipette method which has been adopted by the International Society of Soil Science.

The average figures for the mechanical analyses of the red, intermediate red, intermediate black, black and red sand soils, carried out to date, are given in Table II.

TABLE II.

MECHANICAL ANALYSIS.

Soil Type.	No. of Samples.	Coarse Sand.	Fine Sand.	Silt.	Clay.	Moisture.	$CaCO_3$	Loss in Solution	Total.
Red (Over 700 ft.)	11	0·59	6·17	9·65	70·18	7·61	2·57	1·86	98·65
Intermediate Red (400-700 ft.)	12	1·76	7·60	10·97	68·71	6·38	2·68	1·98	100·08
Intermediate Black (200-400 ft.)	14	2·21	7·58	9·48	65·04	7·46	5·43	2·62	99·83
St. George's Valley (100 ft.)	2	0·83	7·67	10·61	65·06	8·61	4·60	2·05	99·43
Red Sand (100-300 ft.)	4	26·74	36·19	3·67	24·57	2·92	5·38	0·94	100·41
Christ Church Ridge (200-400 ft.)	7	0·85	5·15	9·50	67·49	9·39	6·24	2·61	101·23
Black (0 - 200 ft.)	15	2·51	11·24	9·16	59·52	8·80	7·08	2·19	100·50

As would be expected, *the red sand soils* behave in the field as very light sandy soils. These are rapid in action and crops do well in a year of good rainfall, but suffer badly in times of drought. Owing to the large proportion of the fine sand fraction, these soils tend to cake on the surface after rain.

It might be expected from the mechanical analyses given, that the red soils with their higher percentage of clay would be "heavier" than the black soils. This is quite contrary to practice; the red soils behave definitely as though they contain less colloidal matter than the black soils. They are more easily worked after rain and are much more quickly affected by drought conditions.

(3) INDEX OF TEXTURE.

The index of texture figure has been put forward by Hardy (4) as a single value constant for assessing soil texture. The index of texture of a soil is equivalent to the moisture content at the point of stickiness, less twenty per cent. of the mass of the sand content of the soil.

Keen & Coutts (5) have shown that the "sticky point" of a soil is largely controlled by the organic and inorganic colloidal matter in the soil.

The mean index of texture figures for the various soil types under consideration, together with maximum and minimum figures, are set out in Table III.

TABLE III.

INDEX OF TEXTURE.

Soil Type.	No. of Samples.	Mean	Minimum.	Maximum.
Red (over 700 feet)	75	33.2	29.8	41.6
Intermediate Red (400—700 ft.)	43	32.6	29.0	36.0
Intermediate Black (200–400 ft)	50	34.5	26.4	41.1
St. George's Valley (100 ft.) ..	18	34.2	32.4	39.0
Red Sand (100—300 ft.) ..	21	13.3	6.5	25.0
Black (0—200 ft.)	44	35.8	29.8	42.4

It will be noted that, with the exception of the red sand soils, there is very little difference between the index of texture figures for the various soil types. This is in fair agreement with the mechanical analyses already given, but does not agree with the behaviour of the soils in the field. As already mentioned, the black soils are definitely of a "heavier" nature than the red soils.

CHEMICAL CHARACTERISTICS.

(1) CARBON.

The carbon figure has been determined by a modification of Hardy's (6) wet combustion method.

The mean figures for the estimations carried out on the various soil types together with their standard errors are given in Table IV.

TABLE IV.

CARBON.

Soil Type.	No. of Determinations.	Mean Percentage of Carbon.	Standard error of mean.
Red (over 700 ft.)	10	1.57	± 0.090
Intermediate Red (400—700 ft.) ..	5	1.48	± 0.064
Intermediate Black (200—400 ft.) ..	11	1.33	± 0.061
Christ Church Ridge (200—400 ft.) ..	15	0.96	± 0.053
Black (0—200 ft.)	18	1.13	± 0.042

A consideration of the figures given in Table IV, shows quite clearly that the average percentage of carbon in the red and intermediate red soils is significantly higher than the mean percentage of carbon in the intermediate black soils. The intermediate black soils contain, on the average, a significantly greater amount of carbon than the black soils and those on the Christ Church dome.

The reason for these differences is undoubtedly due to the different practices adopted in growing sugar-cane on these various soil types. In the red and intermediate red soil areas, the rainfall is sufficient to permit the growing of plant cane and two or three crops of ratoons; in the intermediate black soil areas, plant cane and one or two crops of ratoons are grown; whilst in the black soil areas, little ratooning of cane is possible owing to the drier conditions. The ratooning of cane means that a much larger amount of cane can be produced per arable acre and, as the trash from the sugar-cane is the principal source of soil organic matter, it follows that in ratooning districts, more organic matter is available to return to the soil.

It is evident from the figures given in Table IV, that the difference in colour between the red and black soils is not determined by the relative amount of organic matter in these soil types.

(2) NITROGEN.

Nitrogen has been determined by Ball's modification of the Kjeldahl process (7).

The mean figures, together with their standard errors, which have been obtained for the various soil types are set out in Table V.

TABLE V.

NITROGEN.

Soil Type.	No. of Determinations.	Mean Percentage of Nitrogen.	Standard error of mean.
Red (over 700 ft.)	27	0.218	± 0.0058
Intermediate Red (400—700 ft.) ..	18	0.193	± 0.0052
Intermediate Black (200—400 ft.) ..	14	0.152	± 0.0042
Red Sand (100—300 ft.)	13	0.087	± 0.0055
Christ Church Ridge (200—400 ft.) ..	16	0.129	± 0.0025
Black (0—200 ft.)	29	0.136	± 0.0045

An examination of these figures shows a very similar relationship to the organic matter figures. The red and intermediate red soils contain the greatest amount of nitrogen; the intermediate black soils contain less nitrogen than the red soils, but more than the black soils and those on the Christ Church dome. The red sand soils contain less nitrogen than any of the others; in these light sandy soils, the rate of decomposition of organic matter must be very rapid.

The amounts of nitrogen present in these samples of soil are of interest in view of the practice of heavy pen manuring which has been general in Barbados for over two hundred years. It is evident from a study of these nitrogen figures that there has been no accumulation of nitrogen as a consequence of this manuring; in fact, it would appear that the same or a greater loss of nitrogen is taking place from these soils as from the continuously dunged plot on Broadbalk Field at Rothamsted.

These figures also shed some light on the results of manurial trials which have shown that the residual value for pen manure is small. (11).

(3) CARBON-NITROGEN RATIO.

The mean carbon-nitrogen ratios together with their standard errors for the various soils examined, are set out in Table VI.

TABLE VI.

CARBON-NITROGEN RATIO.

Soil Type.	No. of Determinations.	Carbon Nitrogen Ratio. (Mean).	Standard error of mean.
Red (over 700 ft.)	10	7.8	± 0.44
Intermediate Red (400—700 ft.) ..	5	7.7	± 0.97
Intermediate Black (200—400 ft.) ..	11	8.8	± 0.32
Christ Church Ridge (200—400 ft.) ..	15	7.5	± 0.45
Black (0—200 ft.)	18	9.0	± 0.40

As would be expected from the results of the carbon and nitrogen determinations already discussed, there are no significant differences between the carbon-nitrogen ratios of the various soil types. The ratio varies considerably amongst the different soils as might be expected; but, on the average, it approximates to 8.0. This is lower than that generally accepted for temperate arable soils and agrees with the findings of Jenny (8) who concluded that the carbon-nitrogen ratio of soils becomes more narrow with increasing temperature.

(4) PHOSPHORIC ACID.

(a) *Total Phosphoric Acid.*

The total phosphoric acid was determined by the volumetric ammonium molybdate method after extraction with hydrochloric acid, according to the method adopted by the Agricultural Education Association.

The mean percentages of phosphoric acid in the red and black soils are shown in Table VII. The intermediate red soils have been included with the red soils and the intermediate black and Christ Church Ridge soils with the black. It will be seen that there is no significant difference between the mean percentages of total phosphoric acid in the red and black soils.

TABLE VII.

TOTAL PHOSPHORIC ACID.

Soil Type.	No. of Determinations.	Phosphoric acid per cent.		
		Mean	Maximum.	Minimum.
Red	14	0.2123	0.4112	0.1377
Black	10	0.2097	0.5064	0.0966

(b) *Available Phosphoric Acid.*

At the beginning of these soil investigations, a number of methods of determining the available phosphoric acid were tried out; the results of this investigation were reported elsewhere (9). It was shown that there was a high correlation between the results of all the methods examined and, as a consequence, the phosphoric acid soluble in water was used as a routine method of estimating the available phosphate. The water soluble phosphoric acid was determined by the colorimetric method of Atkins (10) except that Lovibond glasses were compared with standard solutions and used as standards.

(c) *Citric Soluble Phosphoric Acid.*

Inasmuch as the phosphoric acid soluble in 1% citric acid was determined for a number of soils in the initial investigation, the mean figures for red and black soils are given in Table VII for purposes of record. It should be noted that, in these estimations, sufficient citric acid was added to the soil before shaking to give a 1% citric acid solution *after* the free calcium carbonate in the soil had been neutralised.

TABLE VIII.

CITRIC SOLUBLE PHOSPHORIC ACID.

Soil Type.	No. of Determinations.	Citric Soluble Phosphoric Acid % (Mean)	Standard error of mean.
Red	13	0.0198	±0.0039
Black	9	0.0410	±0.0087

It will be seen from the figures given in Table VIII, that the mean citric soluble phosphoric acid content of the black soils is significantly higher than that of the red soils.

(d) *Water Soluble Phosphoric Acid.*

A greater number of water soluble phosphoric acid figures are available and in Table IX the mean figures obtained for various soil types are set out.

TABLE IX.

WATER SOLUBLE PHOSPHORIC ACID.

Soil Type.	No. of Determinations.	Water Soluble Phosphoric acid. p.p. million.	Standard error of mean.
Red (over 700 ft.)	27	0.14	± 0.034
Intermediate Red (400—700 ft.) ..	14	0.29	± 0.038
Intermediate Black (200—400 ft.) ..	12	0.61	± 0.043
Red Sand (100—300 ft.)	6	0.20	± 0.103
Black (0—200 ft.)	16	0.98	± 0.173

A study of these figures shows that the amount of easily soluble phosphoric acid increases from the red soils through the intermediate red, intermediate black to the black soils. The reason for these differences cannot be explained on the grounds of different manurial treatment, since the red and black soils have been treated in very much the same way for two or three hundred years; this is supported by the fact that there is no significant difference between the mean amounts of total phosphoric acid in the soil types.

The explanation of the difference in the ease of solubility of the phosphoric acid which exists in the red and black soils is undoubtedly associated with the free sesquioxides which are found in the red soils. This matter will be dealt with later.

Although the amounts of phosphoric acid soluble in water are extremely small in the red soils, the sugar cane is able to obtain all the phosphate which it needs from these soils. Manurial trials (11) which have been carried out on the coral limestone soils show that sugar cane does not respond to phosphatic fertilizers, either on the red or the black soils.

(5.) POTASH.

(a) *Total Potash.*

All potash determinations have been made by the volumetric cobalti-nitrite method as worked out by Milne (12). The total potash was determined in the solution obtained after extracting the soil with hydrochloric acid according to the official method adopted by the Agricultural Education Association. The mean percentage of total potash in the red and black soils is shown in Table X. It is evident from a study of these figures that there is no significant difference between the mean percentage of total potash in the red and black soils.

TABLE X.

Total Potash.

Soil Type	No. of Determinations	Total Potash (per cent.)		
		Mean	Maximum	Minimum
Red	13	0.1260	0.1849	0.0631
Black	10	0.1341	0.1951	0.0947

(*b*) *Available Potash.*

The amounts of potash soluble in 1% citric acid, 1% oxalic acid and the amounts of potash replaced by leaching with a solution of ammonium chloride, were determined on a number of soil samples in the early stages of these soil investigations. As a result of these determinations, it was decided (9) to utilise the exchangeable potash figure as a measure of the available potash in these soils. For purposes of record, the average percentages of potash soluble in 1% citric acid in some typical red and black soils are given in Table XI. It should be noted that in these determinations sufficient citric acid was added to give a 1% solution of free acid after allowing for the neutralisation of the calcium carbonate present in the sample.

TABLE XI.

CITRIC SOLUBLE POTASH.

Soil Type	No. of Determinations.	Mean percentage of citric soluble Potash
Red	15	0.00804
Black	11	0.00797

(*c*) *Exchangeable Potash.*

The exchangeable potash has been determined as a routine operation on all samples of soil taken in the field. The samples were originally leached with normal ammonium chloride, but this solution was later replaced by normal ammonium acetate and the potash in all cases was determined by the volumetric cobalti-nitrite method.

The amounts of exchangeable potash found in soils of the various types are set out in Table XII.

TABLE XII.

EXCHANGEABLE POTASH.

Soil Type	No. of Determinations	Percentage of Exchangeable Potash.		
		Mean	Minimum	Maximum
Red (over 700 ft.)	37	0.0180	0.0097	0.0334
Intermediate Red (400—700 feet.)	16	0.0130	0.0072	0.0226
Intermediate Black. (200—400 feet.)	14	0.0156	0.0082	0.0248
St. George's Valley (100 ft.)	2	0.0146	0.0125	0.0167
Red Sand (100—300 feet).	12	0.0063	0.0031	0.0124
Christ Church Ridge (200—400 feet.)	5	0.0158	0.0118	0.0212
Black (0—200 feet.)	20	0.0211	0.0070	0.0540

It is evident from the figures given in Table XII that the amounts of exchangeable potash in the soils examined are very variable and they serve as good indices of the previous potash manuring of the fields. Manurial trials have shown (11) that, unless adequately supplied with potash, sugar-cane growing on these coral limestone soils is very likely to suffer in yield. Potash deficiency appears to be more likely to occur on the red soils than on the black; this fact has been explained on the assumption that, in the past, ratoon cane has received insufficient supplies of potash in the manure (11). In order to obtain an approximate limiting value for exchangeable potash upon which to base manurial recommendations from soil analyses, the percentages of exchangeable potash in the soil at the various variety trial centres were correlated with the yield of cane (15). From this investigation it was concluded that sugar-cane growing on soil containing less than 0.014% of exchangeable potash would, in all probability, respond to potash manuring.

(6) LIME STATUS.

The calcium carbonate present in the various soil samples examined, has been estimated by Collins's Calcimeter method (14). Free calcium carbonate was

found to be present in all of the surface soils; the average amounts for the different soil types is set out in Table XIII. These figures are slightly different from those in the mechanical analysis data given in Table II, since they are the means of a greater number of determinations.

TABLE XIII.

Soil Type.	No. of Determinations.	Mean Percentage Calcium Carbonate.	Standard error of Mean.
Red .. .. .. (over 700 feet).	38	1.48	± 0.12
Intermediate Red .. (400-700 feet).	22	2.62	± 0.51
Intermediate Black .. (200-400 feet)	24	4.91	± 0.70
Christ Church Ridge .. (200-400 feet)	11	5.41	± 1.45
Red Sand .. .. .. (100-300 feet)	12	1.58	± 0.33
St. George's Valley .. (100 feet)	4	3.85	± 0.89
Black .. .. .. (0-200 feet)	33	6.26	± 0.94

A consideration of these figures shows quite definitely that, on the average, the red soils contain the least amount of calcium carbonate and the amount gradually increases through the intermediate red, intermediate black to the black soils.

It will be noted that the red sand soils are relatively poor in calcium carbonate.

(7) SOIL REACTION.

It would be expected that the coral limestone soils with their reserves of calcium carbonate would be alkaline in reaction. This has proved to be the case for all the surface soils examined. The pH of the soils examined, determined by the quinhydrone electrode method, has varied between 7.2 and 8.5. No acid surface soil has yet been found on the coral limestone area of Barbados.

The exchange acidity has been determined by the method described by Hardy and Lewis (15) and the surface soils have given a pH varying between 7.1 and 7.9. The soils have thus no lime requirement by this method.

(8) COMPOSITION OF CLAY FRACTION.

The clay fractions of the various soil samples were separated after the mechanical analyses and determinations of silica, alumina and iron have been made after fusion with sodium carbonate. The methods of analysis adopted were those described in the official methods of analysis of the Association of Official Agricultural Chemists.

The mean figures obtained for the various soil types are set out in Table XIV, together with the molecular ratios for silica to alumina and silica to sesquioxides.

TABLE XIV.

COMPOSITION OF CLAY FRACTIONS.

Soil Type.	No. of Determinations.	SiO_2 (Mean) %	Al_2O_3 (Mean) %	Fe_2O_3 (Mean) %	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
Red (Over 700 feet.)	17	39·19	26·37	12·13	2·52	1·95
Intermediate Red (400-700 feet.)	10	40·36	24·02	12·03	2·86	2·16
Intermediate Black (200-400 feet.)	12	42·80	22·25	11·29	3·23	2·45
St. George's Valley (100 feet)	3	43·30	21·31	9·47	3·45	2·69
Red Sand (100-300 feet.)	3	43·30	22·78	10·83	3·23	2·48
Christ Church Ridge (200-400 feet.)	8	45·80	18·39	11·47	4·23	3·03
Black (0 -200 feet.)	15	46·36	17·17	10·57	4·59	3·29

An examination of the figures given for the composition of the clay fractions shows quite clearly that there is a gradual increase in the silica content from the high to the low levels. The clays from the soils on the Christ Church ridge are an exception and are only slightly less siliceous than the low level black soils. The clay of the red sand soils and the St. George's Valley soils approximates in composition to the clay of the intermediate black soils.

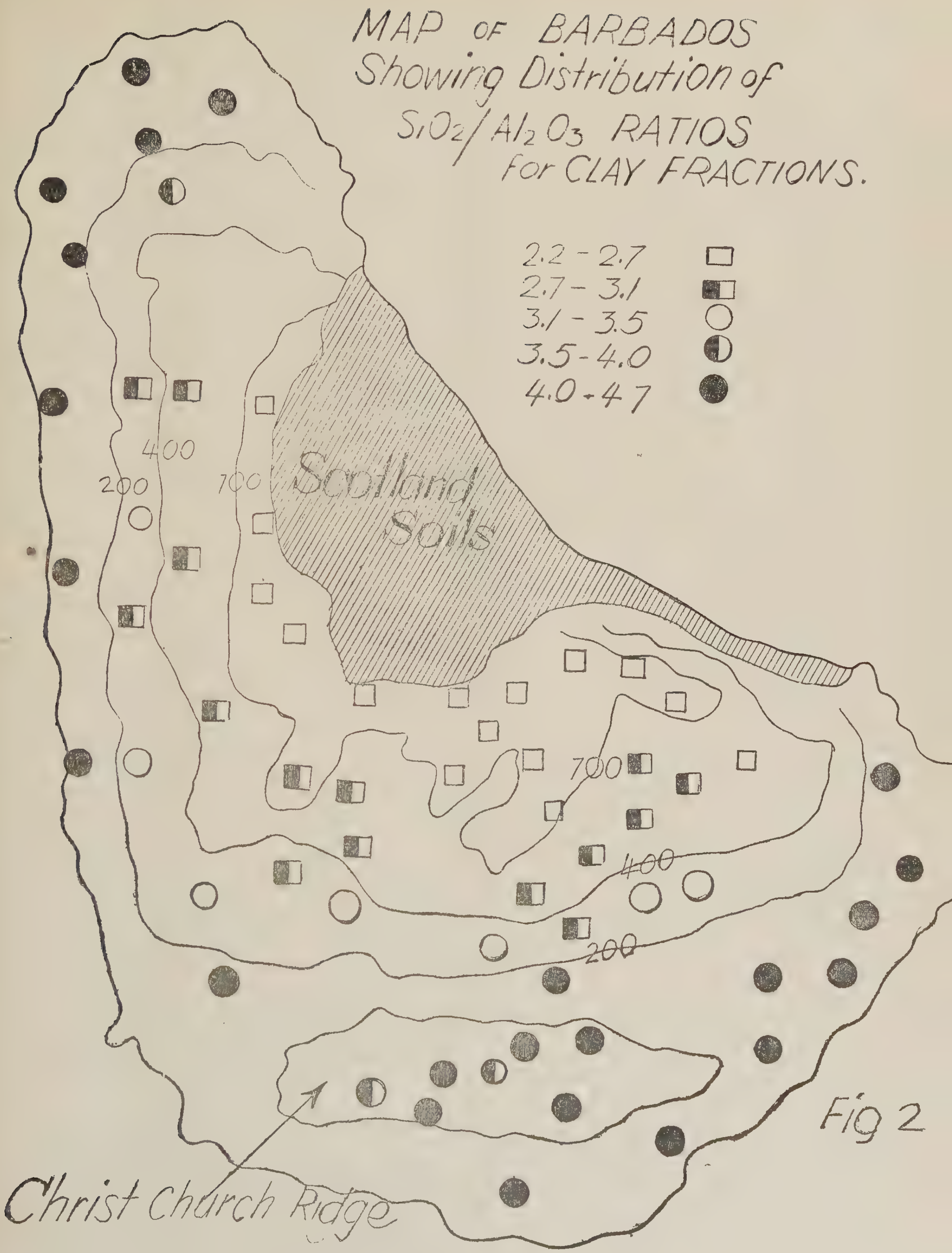

MAP OF BARBADOS
Showing Distribution of
SiO_2/Al_2O_3 RATIOS
For CLAY FRACTIONS.
2.2 - 2.7
2.7 - 3.1
3.1 - 3.5
3.5 - 4.0
4.0 - 4.7
400
200
700
Scotland Soils
700
400
200
Christ Church Ridge

Fig 2

The silica-alumina ratios of the clay fractions mark out the various soil types met with on the coral limestone formation with considerable precision. In Fig. II is given a map of Barbados showing the 200 ft., 400 ft., and 700 ft. contours and the silica-alumina ratios of the clay fractions of the various soil samples examined. It will be noted that red, intermediate red, intermediate black, black and the Christ Church ridge soils occupy fairly definite positions according to elevation above sea-level.

If it is assumed that the various soil types represent different stages of development of the same original material and it is further assumed that there has been no loss of alumina in the weathering processes, then it is possible to calculate the losses of silica and iron during the transformation of the black soil into the red. These figures are set out in Table XV, where it is seen that in this hypothetical weathering, the principal losses have fallen on the silica and that there have been smaller but appreciable losses of iron.

TABLE XV.

Soil Type.	SiO_2	Per cent. Lost.	Al_2O_3	Per cent. Lost.	Fe_2O_3	Per cent. Lost.
Red (Over 700 feet.)	25·52	44·96	17·17	0	7·90	25·26
Intermediate Red (400-700 feet.)	28·85	37·78	17·17	0	8·60	18·64
Intermediate Black (200-400 feet.)	33·03	28·76	17·17	0	8·71	17·60
St. George's Valley (100 feet.)	34·90	24·74	17·17	0	7·63	27·81
Red Sand (100-300 feet.)	32·64	29·60	17·17	0	8·16	22·80
Christ Church Ridge (200-400 feet.)	42·75	7·80	17·17	0	10·71	1·35
Black 0 - 200 feet	46·36	0	17·17	0	10·57	0

(9) COMPOSITION OF FINE SAND FRACTIONS.

The fine sand fractions from the various samples submitted to mechanical analysis were also separated and the total silica, alumina and iron have been determined in a number of these by the same methods as were adopted in analysing the clay fractions.

The percentage of fine sand in these soils, with the exception of the red sands, is relatively small, varying from about 6% in the red soils down to about 11% in the black soils.

The mean figures which have been obtained for the various soil types are set out in Table XVI, together with the molecular ratios for silica to alumina and silica to sesquioxides.

TABLE XVI.

COMPOSITION OF FINE SAND FRACTIONS.

Soil Type,	No. of Determinations.	SiO_2 (Mean) %	Al_2O_3 (Mean) %	Fe_2O_3 (Mean) %	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
Red (Over 700 feet.)	8	59·24	7·49	19·00	13·45	5·14
Intermediate Red (400-700 feet.)	8	55·47	8·48	19·00	12·59	4·58
Intermediate Black (200-400 feet)	5	61·89	4·22	15·15	24·95	7·59
St. George's Valley (100 feet.)	2	65·20	4·92	14·96	22·54	7·67
Christ Church Ridge (200-400 feet.)	4	64·49	3·01	14·47	36·42	8·96
Black (0 - 200 feet.)	8	80·14	2·73	7·38	49·90	18·33

The figures given in Table XVI for the composition of the fine sand fractions show similar graded differences between the various soil types as do the figures obtained for the clay fractions. As would be expected, the fine sand fractions are more siliceous than the clays, but the most striking difference is in the ratio of alumina to iron. In the clay fractions there is approximately twice as much alumina as oxide of iron, whilst in the fine sand fractions there is about three times as much iron oxide as alumina.

If it is assumed that the composition of the fine sand fractions of the various soil types was originally the same and that the differences shown in Table XVI are due to weathering, then it is possible to calculate the losses of silica and iron which have taken place on the assumption that there has been no loss of alumina during the various weathering processes. This is shown in Table XVII.

TABLE XVII.

Soil Type.	SiO_2	Per cent. Lost.	Al_2O_3	Per cent. Lost.	Fe_2O_3	Per cent. Lost.	Per cent. Gained.
Red (Over 700 feet)	21·60	73·05	2·73	0	6·92	6·25	
Intermediate Red (400-700 feet)	17·86	77·82	2·73	0	6·12	17·07	...
Intermediate Black (200-400 feet)	40·04	50·05	2·73	0	9·80	...	32·80
St. George's Valley (100 feet)	36·18	54·86	2·73	0	8·30	...	12·50
Christ Church Ridge (200-400 feet)	58·50	27·00	2·73	0	13·12	...	77·80
Black (0 - 200 feet)	80·14	0	2·73	0	7·38	0	...

An examination of the data given in Table XVII shows up the very great difference in the silica content of the fine sand fractions of the red and black soils and indicates the big loss which has taken place in this weathering.

(10) SATURATION CAPACITY.

As already mentioned, exchangeable potash was determined in most soils by leaching with neutral ammonium acetate; the leached soil was subsequently washed with water and finally with neutral alcohol and the total ammonia absorbed by the soil was determined by distillation.. This method has been used by Kelly and Brown (16) and by Chapman and Kelly (17) as a measure of the "Base-exchange capacity" or "Saturation capacity" of the soil.

The "saturation capacities" of the different soil types determined by this method and expressed in mgm. E. per 100 grm. soil are set out in Table XVIII.

TABLE XVIII.

"SATURATION CAPACITIES."

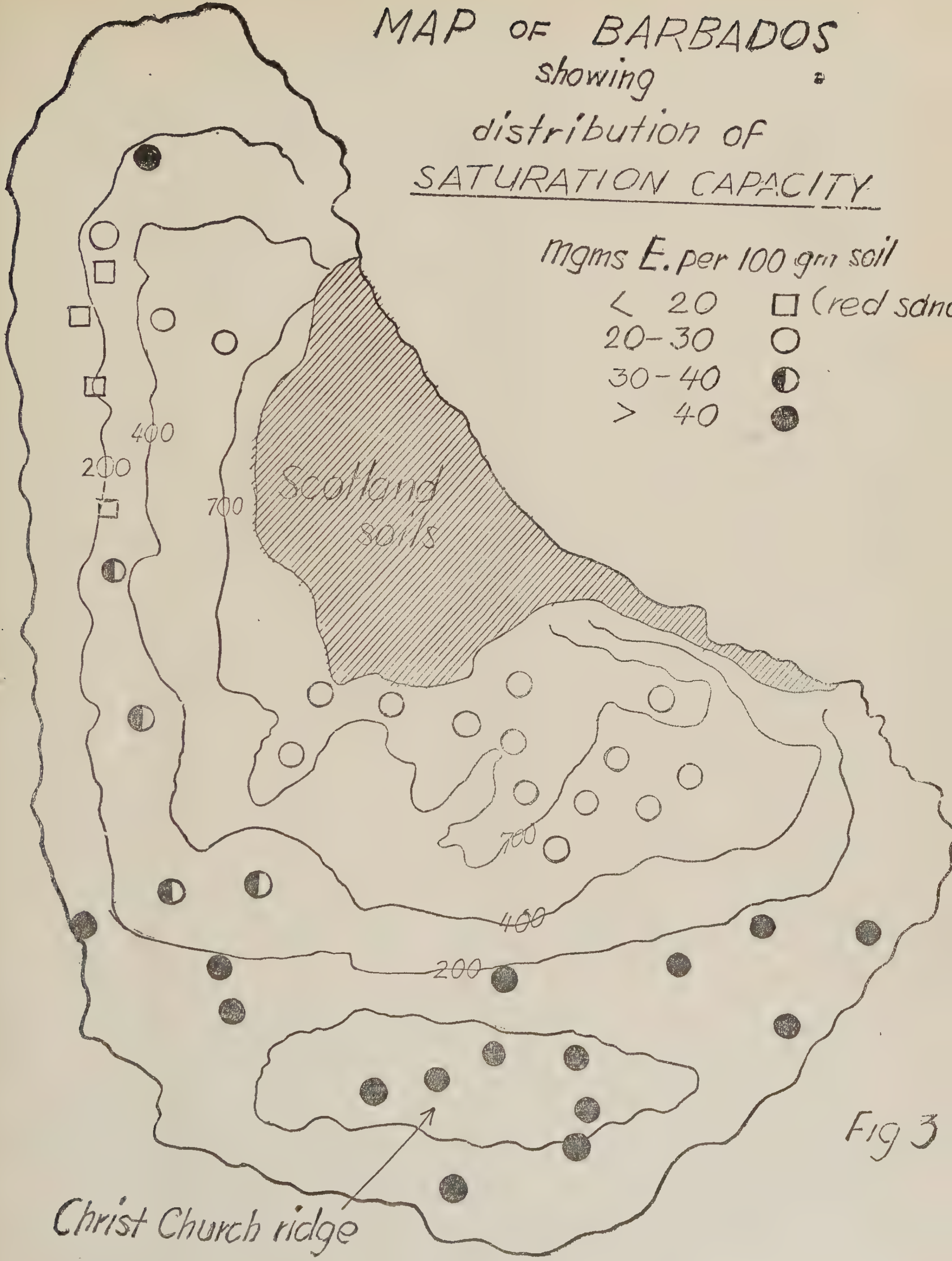
Soil Type.	No. of Determinations.	Saturation Capacity Mgm. E. per 100 grm. Soil.
Red .. .. .. (over 700 feet).	27	27.1
Intermediate Red .. (400-700 feet).	13	28.1
Intermediate Black .. (200-400 feet)	9	37.3
St. George's Valley .. (100 feet)	2	35.8
Red Sand .. .. .. (100-300 feet)	15	17.1
Christ Church Ridge .. (200-400 feet)	5	54.1
Black .. .. .. (0-200 feet)	15	50.2

These figures again bring out the graded differences which exist as we pass from the red, through the intermediate to the black soils. Although the red soils have a slightly higher clay and organic matter content than the black soils, they have a much lower base-exchange capacity. This is undoubtedly associated with the lower silica-sesquioxide ratio which has been shown to exist in the clay fraction of the red soils.

Owing to their relative low clay content, the base exchange capacity of the red sands is low as would be expected.

In Fig. III is given a map of Barbados showing the distribution of the "saturation capacities" of the soils examined and it will be noted that the various soil types are marked out in the same manner as in Fig. II, where the distribution of the silica-alumina ratio of the clay fractions is given.

For purposes of comparison the saturation capacities of eight soils were determined by three other methods, viz., (1) Crowther & Basu's (18) modification of Page & William's method (19) in which the soil is saturated with calcium carbonate, leached with sodium chloride solution and the calcium determined in the


MAP OF BARBADOS
showing
distribution of
SATURATION CAPACITY
mgms E. per 100 gm soil
< 20 □ (red sand
20-30 ○
30-40 ◐
> 40 ●
400
200
700
Scotland soils
700
400
200
Christ Church ridge
Fig 3

filtrate; (2) Rice Williams method (20) in which the free carbonate which is in equilibrium with the soil, is determined by decomposition with acetic acid and the bases replaceable by further leaching with acetic acid are determined; (3) Bray & Willhite's method (21) in which the soil is leached with neutral ammonium acetate solution, the filtrate is taken to dryness and heated, which converts the acetates of the replaced bases into carbonates. The carbonates are titrated as a measure of the total replaceable bases. This method was included, since the leaching with neutral ammonium acetate was necessary in the Kelly method.

The results of these determinations are given in Table XIX.

TABLE XIX.

Soil Type.	Soil Number.	% Calcium Carbonate.	Saturation Capacity.(Mgm. E. per 100 grm Soil.)			
			Chapman & Kelly.	Crowther & Basu.	Rice Williams.	Bray & Willhite.
Red (Over 700 feet.)	4/32	8·75	17·2	27·4	66·3	28·2
Red (Over 700 feet.)	8/32	2·48	22·8	24·5	31·1	37·8
Red (Over 700 feet.)	34/32	0·50	31·0	39·7	39·1	35·4
Red (Over 700 feet.)	39/32	3·71	27·8	36·4	37·2	35·6
St. George's Valley (100 feet.)	15/32	3·33	35·9	47·2	49·7	42·6
Red Sand (100 300feet)	19/32	2·24	10·6	17·8	13·8	22·2
Black (0 - 200 feet.)	11/32	11·45	52·2	59·0	88·8	59·6
Scotland	44/32	6·75	43·8	52·2	55·6	45·8

A consideration of these figures shows that whatever method of determining the saturation capacity is adopted, the same relative differences are to be found between the various soils examined. There can be no doubt, therefore, that there is a very real difference in the saturation capacities of the red and black soils. As would be expected, the Chapman & Kelly method gives lower results than the other methods. The leaching solution in the Chapman and Kelly method is at pH 7.0 and the saturation capacity by this method represents the amount of base held by the soil when leached with a solution of this reaction. In the Crowther & Basu and the Rice Williams methods, the soil capacity is determined after the soil has reached equilibrium with calcium carbonate, i.e. at a reaction corresponding to a pH of about 8.3.

Two soils, viz., 4/32 and 11/32 repeatedly gave abnormally high results by the Rice Williams method for some reason which, at present, is unexplained.

In the Bray & Willhite method, the calcium carbonate soluble in the leaching solution will be included with the total replaceable bases and will therefore give, with the soils examined, higher results than the Chapman & Kelly method.

SOIL PROFILE STUDIES.

There are no soils in Barbados in which the natural profile development has not been interfered with by cultivation. An examination, however, has been made of the profiles of a number of cultivated soils and the information, although it must be regarded as of a preliminary nature, is here recorded.

(1) RED SOILS.

The red soils, by which is meant those soils above 700 feet, do not all possess the red colour which might be expected from their designation; some of the surface soils are more chocolate brown or even darker in colour. In sampling soils in the earlier soil investigations, it was customary to take a core of the subsoil for inspection. In this way, it was found that the reddest of the red soil type had generally a red and white mottled subsoil; the less red soils, on the other hand, generally possessed a yellowish brown subsoil. It should be noted that in the red and white mottled subsoils, streaks of the yellowish brown clay were generally noticeable.

The following profiles are typical of the more distinct types of red soil.

(a) *Blackmans I.*

TABLE XX.

PLANTATION BLACKMANS. Altitude 900 feet.

Soil No.	Depth.	Description.	Nitrogen %	Organic Carbon %	Calcium Carbonate %	pH.	Exchange Acidity (Hardy & Lewis.)	Clay. %
4/32	0— 9″	Typical reddish brown surface soil.	0·105	1·27	8·8	7·5	6·9	69·9
5/32	9—18″	Mottled red and white clay, more red than white.	0·029	0·15	0·1	7·5	6·8	76·7
6/32	18—21″	Mottled red, white and brown clay.	0·040	0·10	0·1	7·3	6·8	79·9
7/32	21—30″	Mottled red, white and brown clay, with more brown streaks.	0·039	0·11	0·1	7·2	6·8	81·6

The composition of the clay and fine sand fractions in the various horizons is given in the following tables.

TABLE XXI.

COMPOSITION OF CLAY FRACTION.

Depth.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0— 9″	37·50	26·17	10·68	2·43	1·93
9—18″	38·86	29·16	11·34	2·26	1·81
18—21″	36·68	28·10	9·30	2·22	1·83
21—30″	37·98	31·93	9·77	2·02	1·69

TABLE XXII.

COMPOSITION OF FINE SAND FRACTIONS.

Depth.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0— 9″	42·20	11·56	30·24	6·19	2·32
9—18″	39·90	17·01	30·24	3·98	1·87
18—21″	35·28	13·85	32·55	4·32	1·73
21—30″	33·78	14·63	33·12	3·92	1·60

(b) *Blackmans II.*

The field from which this profile was taken was about a quarter of a mile from the preceding one. The subsoil in this field was a brownish yellow colour and did not show the red and white mottling of Blackmans No. I.

TABLE XXIII.

PLANTATION BLACKMANS. Altitude 900 feet

Soil No.	Depth.	Description.	Nitrogen. %	Organic Carbon %	Calcium Carbonate %	pH.	Exchange Acidity (Hardy & Lewis.)	Clay. %
8/32	0— 9″	Chocolate brown surface soil.	0·193	1·42	2·5	8·1	7·2	73·3
9/32	9—18″	Brownish yellow clay.	0·111	0·51	0·5	7·9	7·1	83·7
10/32	18—27″	Brownish yellow clay.	0·095	0·45	0·3	7·9	7·1	85·6

Coral rock at about 3 feet.

The composition of the clay and fine sand fractions at the three different depths is given in the following tables.

TABLE XXIV.

COMPOSITION OF CLAY FRACTION.

Depth.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0— 9″	34·32	23·33	11·97	2·50	1·88
9—18″	35·24	31·71	13·39	1·89	1·49
18—27″	35·64	28·96	12·44	2·09	1·64

TABLE XXV.

COMPOSITION OF FINE SAND FRACTION.

Depth.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0— 9″	56·30	8·06	21·49	11·85	4·39
9—18″	58·14	4·38	21·02	22·43	5·55
18—27″	64·55	6·41	22·44	17·09	5·29

(c) *Colleton.*

This estate is in the red soil area and a profile was taken on what is known to the practical man as "a black soil on a red soil estate."

TABLE XXVI.

PLANTATION COLLETON Altitude 750 feet.

Soil No.	Depth.	Description.	Nitrogen %	Organic Carbon %	Calcium Carbonate %	pH.	Exchange Acidity (Hardy & Lewis.)	Clay. %
34/32	0—12″	Dark brown surface soil.	0·150	0·98	0·5	7·9	7·5	67·0
35/32	12—24″	Black subsoil.	0·132	0·73	0·1	7·9	7·5	64·7
36/32	24—36″	Black subsoil.	0·146	0·87	0·1	7·8	7·5	68·8
37/32	36—48″	Yellowish brown clay.	0·099	0·56	0·1	7·4	6·8	84·0
38/32	48—52″	Yellowish brown clay.	0·092	0·48	0·1	7·7	6·9	79·9

Coral rock at about 54 inches.

The composition of the clay and fine sand fractions in the soils from the various depths sampled, is given in the following Tables.

TABLE XXVII.

COMPOSITION OF CLAY FRACTIONS.

Depth.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0—12″	40·34	27·62	9·93	2·48	2·02
12—24″	40·12	24·72	11·18	2·75	2·14
24—36″	39·18	25·03	13·87	2·66	1·96
36—48″	39·04	26·66	10·24	2·49	2·00
48—52″	39·62	24·15	10·40	2·78	2·19

TABLE XXVIII.

COMPOSITION OF FINE SAND FRACTIONS.

Depth.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0–12″	59.96	12.99	16.91	7.84	4.28
12–24″	61.16	10.95	18.65	9.48	4.54
24–36″	67.32	7.02	19.28	16.28	5.91
36–48″	66.56	6.27	20.38	18.01	5.86
48–52″	67.62	6.83	20.07	16.80	5.84

A study of these profile figures shows a definite mechanical eluviation in the three red soils examined; there is an increase in the clay fraction with depth.

It is difficult to state definitely whether the calcium carbonate present in these red soils has been artificially added or not. At the present day, it is not customary to lime any of the coral limestone soils but, from enquiries which have been made of the older planters, it would appear that ''marling'' was a fairly general agricultural occupation fifty or a hundred years ago.

The relatively high calcium carbonate content of Blackmans No. I. soil, associated as it is with an almost carbonate free subsoil, suggests that this soil has been "marled." It is significant that the surface soil and all the other samples in this profile have a slight exchange acidity. Colleton soil has also a slight exchange acidity at depths below 36 inches.

It is generally agreed that the production of red limestone soils is associated with a desaturation of the soil and an acid reaction and the suggestion is made that under the original forest conditions, these upland soils were base unsaturated and consequently acid. The subsequent liming and marling which have taken place since these soils came under cultivation, have saturated the soils again and given a reserve of calcium carbonate to the surface soils.

The composition of the clay fractions does not appear to vary to any significant extent either in the profile or from soil to soil, although there is some indication in both the Blackman profiles that the clay fraction of the surface has a somewhat wider silica-alumina ratio than the clay fractions of the subsoils.

The fine sand fractions show decided variations in composition with depth in all the three types examined. In Blackmans No. I which is a typical red soil with a mottled red and white subsoil, the fine sand has a high iron content which increases with depth. In Blackmans No. II which is a chocolate brown soil with a brownish yellow subsoil, the fine sand fractions are much more siliceous than Blackmans No. I. and the silica and iron content both increase with depth. In the Colleton soil which is still darker in colour, with a yellowish brown clay subsoil, the fine sand fractions are somewhat similar in composition to Blackmans No. II. and show the same increase in the silica and iron content with depth.

The development of the red and white mottled subsoil would, from the results of analyses so far undertaken, appear to be associated with a fine sand fraction with a comparatively low silica and high iron content and would apparently indicate a further stage in development. The reason for this greater development is probably associated with a greater acidity and base unsaturation under the original conditions.

A microscopical examination of the fine sand fractions from these red soils shows that some of the particles are brownish red and others yellowish red in colour. There are a few black particles present and some transparent and white opaque particles. The red colour is due to a film of oxide of iron around the particle; this film is removed by warming with moderately strong hydrochloric acid and white opaque particles are produced. It is found that the redder the soil, the larger the proportion of fine sand particles which have this red film.

2. ST. GEORGE'S VALLEY SOIL.

One soil of the St. George's Valley type has so far been examined in profile. The following data were obtained on the samples taken.

TABLE XXIX.

PLANTATION CARRINGTON Altitude 120 feet.

Soil No.	Depth.	Description.	Organic Carbon %	Nitrogen %	Calcium Carbonate. %	pH.	Exchange Acidity (Hardy & Lewis.)	Clay. %
15/32	0— 9″	Black surface soil.	0·60	0·094	3·3	7·9	7·4	61·6
16/32	9—21″	Brownish with greyish white streaks.	0·45	0·056	0·4	7·5	7·0	70·5
17/32	21—33″	Bluish white clay with brownish streaks..	0·22	0·049	0·2	6·8	6·4	74·3
18/32	33—45″	Bluish white clay with brownish streaks.	0·21	0·039	0·0	5·3	5·0	73·8

The data recorded in Table XXIX is of special interest in that they show the acid nature of the subsoil clay in this particular profile; the acidity increases with depth.

It has been customary even up to the present to lime these valley soils in order to improve their texture and, in all probability, the alkalinity of the top 21 inches is due to the applications of lime and marl during the years these soils have been under cultivation. As already indicated, these valley soils have been formed by the washing down of soil material from the surrounding highlands and, doubtless, much of the accumulation took place before the St. George's Valley was elevated above sea-level.

The rise in the clay content indicates a mechanical eluviation.

The compositions of the clay fractions together with the silica-alumina and silica sesquioxide ratios are given in Tables XXX and XXXI.

TABLE XXX.

COMPOSITION OF CLAY FRACTION.

Depth.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0– 9″	42.26	21.86	9.14	3.28	2.59
9–21″	41.80	21.26	9.14	3.34	2.62
21–33″	41.70	19.70	8.35	3.60	2.84
33–45″	41.90	20.25	9.45	3.51	2.70

The composition of the fine sand fractions are set out in Table XXXI.

TABLE XXXI.

COMPOSITION OF FINE SAND FRACTIONS.

Depth.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0– 9″	67.92	3.81	16.64	30.25	7.99
9–21″	57.22	4.31	26.69	22.53	4.55
21–33″	51.86	4.45	30.15	19.78	3.72
33–45″	46.80	6.85	31.25	11.59	2.96

It will be noted from the figures given in Table XXX that there is very little variation in the composition of the clay fraction with depth. The silica-alumina ratios of the clays of these valley soils are similar to those of the intermediate black soils.

The figures for the fine sand fractions, however, show a very considerable variation. It will be noted that the iron content increases from 16.6% to 31.3% through the profile; there is also a slight, but appreciable increase in the alumina, and a corresponding decrease in the silica content. This increase in the sesquioxide content of the fine sand is associated with an increase in the acid reaction of the soil material

3. RED SAND SOIL.

The profile of a typical red sand soil has been examined with the following results:—

PLANTATION SIX MENS. Altitude 200 feet.

Soil No.	Depth.	Description.	Organic Carbon %	Nitrogen %	Calcium Carbonate %	pH.	Exchange Acidity (Hardy & Lewis.)	Clay. %
19/32	0—12″	Surface soil, brownish in colour.	0·54	0·042	2·24	8·4	7·5	17·7
20/32	12—15″	Similar to surface soil, without organic matter.	0·29	0·025	1·59	8·2	7·4	14·1
21/32	15—25″	Very black and coarse textured.	0·26	0·039	0·0	7·6	7·0	23·2
22/32	25—37″	Yellowish brown clay, with bluish white streaks.	0·15	0·038	0·0	7·4	6·8	35·3
23/32	37—48″	Yellowish brown clay, with bluish white streaks.	0·05	0·026	0·0	7·4	6·8	47·3

The data recorded in Table XXXII shows a very decided mechanical eluviation. This profile shows that below 25″ and the advent of a yellowish brown clay, a slight exchange acidity develops. It will also be noted that the calcium carbonate content decreases with depth indicating that this material has been artificially added.

The composition of the clay fractions together with the silica-alumina and silica sesquioxide ratios are given in Table XXXIII.

TABLE XXXIII.

COMPOSITION OF CLAY FRACTION.

Depth	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0—12″	43.14	21.36	11.34	3.43	2.56
12—15″	43.02	19.07	10.08	3.83	2.86
15—25″	42.30	19.10	9.45	3.76	2.86
25—37″	39.42	22.68	9.77	2.95	2.31
37—48″	40.68	27.95	10.55	2.47	1.99

Consideration of the figures given in Table XXXIII shows that there is little variation in the composition of the clay fraction down to a depth of 25″. Below this where a much heavier yellowish brown clay is met with, the clay content increases considerably and the silica-alumina ratio of this clay becomes narrower, owing to the increase in the alumina content.

The sand fractions were very siliceous, appearing to consist chiefly of quartz particles, and were not analysed in detail.

4. BLACK SOILS.

Two black soil profiles were examined, the first—Codrington—is representative of the shallow type of black soil, high in calcium carbonate; the second—Groves—is representative of the deeper type of black soil.

Particulars of the Codrington profile are given in Tables XXXIV and XXXV.

TABLE XXXIV.

Plantation Codrington. Altitude 180 feet.

Soil No.	Depth.	Description	Organic Carbon %	Nitrogen. %	Calcium Carbonate %	pH	Exchange Acidity (Hardy & Lewis)	Clay %
11/32	0—12″	Typical black surface soil.	1·20	0·140	11·45	8·5	7·5	60·3
12/32	12—24″	Yellowish brown clay mixed with small calcareous granules.	0·50	0·092	24·95	8·5	7·4	56·8
13/32	24—33″	Yellowish brown clay and calcareous rubble mixed together.	0·24	0·069	61·50	8·5	7·1	29·9
14/32	33—39″	White and more calcareous.	0·18	0·049	75·11	8·5	7·2	21·3

Soft coral limestone rock below.

The calcium carbonate increases from 11.45% up to 75% from the surface soil down to the coral rock and is undoubtedly derived from the underlying limestone. The clay content when calculated on a calcium carbonate free basis increases through the profile indicating a mechanical eluviation.

The composition of the clay fractions together with the silica-alumina and silica-sesquioxide ratios are given in Table XXXV.

TABLE XXXV.

COMPOSITION OF CLAY FRACTIONS.

Depth.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0–12″	42.26	17.00	9.30	4.22	3.13
12–24″	44.56	18.89	9.61	4.00	3.02
24–33″	42.30	18.70	9.45	3.84	2.91
33–39″	42.36	21.42	9.43	3.36	2.59

The second profile taken in a field at Groves plantation showed a typical black surface soil down to a depth of twelve inches. The second twelve inches was typical subsoil; the colour was black with greyish streaks. The third twelve inches was a soapy greyish white coloured clay with black streaks through it. Small black concretions were seen in this layer ranging in size from a pin's head up to that of a small pea. These concretions were very similar to the black streaks already noted, and it appeared that the black colour of the surface soil might be due to the same factor which imparted the black colour to the concretions. A number of these small nodules were collected and analysed separately; the results are recorded in Table XXXVII.

The particulars of the profile are as follows:—

TABLE XXXVI.

PLANTATION GROVES. Altitude 120 feet.

Soil No.	Depth	Description	Organic Carbon %	Nitrogen %	Calcium Carbonate %	pH	Exchange Acidity (Hardy & Lewis.)	Clay. %
65/34	0—12″	Typical black surface soil.	1·09	0·051	4·8	8·1	7·2	60·7
66/34	12—24″	Black subsoil with greyish white streaks	0·67	0·056	3·7	8·1	7·0	68·6
67/34	24—36″	Greyish white soapy clay with black streaks and small black concretions.	0·58	0·015	5·8	8·1	7·0	73·0

The analyses given in Table XXXVI show a decided mechanical eluviation and also show the presence of free calcium carbonate throughout the profile. This carbonate, as for the Codrington soil, would indicate that the black soils were not leached of free carbonate or made acid under the original conditions. They have, therefore, probably been little altered by weathering agents since they were formed.

The composition of the clay fractions and of the black concretions, together with the silica-alumina and silica-sesquioxide ratios are given in Table XXXVII.

TABLE XXXVII.

COMPOSITION OF CLAY FRACTIONS.

Depth.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0–12″	45.12	16.93	9.32	4.52	3.34
12–24″	45.89	17.06	9.60	4.57	3.36
24–36″	46.05	18.79	9.58	4.16	3.14
Black concretions.	43.68	14.03	15.05	5.29	3.14

It will be noted from the figures given in Table XXXVII that the composition of the clay fraction at the various depths shows little variation.

The black concretions are much more ferruginous than the clay fractions and since the black colour of these soils appears associated with the black streaks and concretions appearing in this subsoil clay, it would appear that the colour is associated with the state in which this excess iron exists in the soil.

The blackness of the 12—24″ layer of this profile is definitely not due to the calcium status of the humus as has been suggested by Robinson (22) since there is little or no organic matter present.

The composition of the fine sand fractions in the various sections examined in the Groves soil together with the silica-alumina and silica-sesquioxide ratios are given in Table XXXVIII.

TABLE XXXVIII.

COMPOSITION OF FINE SAND FRACTIONS.

Depth.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	SiO_2/Al_2O_3	SiO_2/R_2O_3
0–12″	87.14	3.64	4.16	40.62	23.50
12–24″	90.81	1.70	4.01	90.93	36.28
24–36″	90.22	3.12	2.91	49.20	30.80

It will be noted from Table XXXVIII that the fine sand fractions are very siliceous and show little variation with depth. This again indicates that these black soils have been little affected by weathering agents.

A microscopical examination under reflected light shows that most of the fine sand particles from the black soils are transparent, white and opaque, or black in colour. A few particles are yellowish or reddish brown in colour, similar to the iron stained particles which are so noticeable when the fine sand fractions of the red soils are examined.

Most of the black particles obtained after grinding the concretions found in the Groves subsoil yielded iron to the solution when treated with concentrated hydrochloric acid in the cold and became white and opaque in appearance. Some of the particles remained black and apparently unaffected even after boiling with concentrated hydrocholoric acid for five minutes.

THE RELATIONSHIP BETWEEN THE RED AND THE BLACK CORAL LIMESTONE SOILS.

INTRODUCTION.

Consideration of the data which have been advanced in this paper shows that the coral limestone soils of Barbados can be grouped into seven principal types. The soil types which have been derived from the underlying coral rock with the addition of volcanic ash, are five in number and have been designated the *red*, the *intermediate red*, the *intermediate black*, the *Christ Church ridge* and the *black soils.*

The other two soil types are the *red sand* and the *St. George's Valley* soils. The red sand soils are characterised by a high percentage of quartz sand which would appear to have originated in the Scotland district. The clay fraction of the red sand soils is very similar in composition to that of the intermediate black soils which are found at a similar elevation. The St. George's Valley soils are deep and appear to be made up very largely of material washed down from the surrounding higher land. This is suggested by their depth and by the composition of the clay fraction which approximates in composition to the intermediate black soils. The red sand and the St. George's Valley soils cover a relatively small area of the island.

Four of the five typical coral limestone soils are also grouped according to the elevation at which they are found. There is, of course, no sharp line of demarcation at any particular elevation but, approximately, it can be said that the red soils occur about 700 feet, the intermediate red soils at between 400 and 700 feet, the intermediate black soils at between 200 and 400 feet and the black soils at between sea level and 200 feet. The Christ Church ridge soils are an exception, since although they are found at an elevation of between 200 and 400 feet, they resemble the black soils more closely in properties than the intermediate black soils which are found at a corresponding elevation on the main part of the island.

According to Trechmann (2) who has postulated the most recent theory of the formation and elevation of the coral limestone, the coral rock was formed over the whole of Barbados before the uplift commenced. He considers that the uplift has been an oblique or differential one; the higher part of the island has

been tilted or thrust towards the east and north, followed by later repeated uprising with slighter tilting; the southern Christ Church dome is a later independent uplift, apparently with a thrust from the south. He further points out that the mollusca in the coral rock at high levels do not seem to differ from those at medium or low levels; but even at low levels a certain number show perceptible differences from the living species.

According to this view of the elevation and uplift of the coral limestone formation, there is no reason why the weathering of the limestone should not yield an identical original soil material. It also follows that the soils which have been longest exposed to atmospheric conditions will be the most mature; hence, the oldest soils will be those found at the greatest elevation. It is, therefore, not surprising that the physical and chemical properties of the various soil types correspond with their elevation above sea-level. The reason why the soils of the Christ Church ridge are less weathered than the soils at the same elevation on the main part of the island is explicable on the geological evidence of Trechman. The properties of the soils on the Christ Church ridge yields evidence in support of Trechmann's view of the uplift of the island.

All the available evidence, then, points to the fact that the main grounds of difference between the red and black soils are to be found in the different degrees of weathering which these soils have experienced; and a study of the various soil types gives an interesting demonstration of the various stages in the development which has taken place in these limestone soils.

The analytical data presented in this paper shows that the chief changes which have been affected by the various weathering processes are as follows.

1. PHYSICAL CHANGES.

(a) *Colour.*

The most obvious physical change has been in colour. The least weathered soils are black in colour with a yellowish or greyish white subsoil; in the case of the Groves subsoil black streaks and concretions were found. The most weathered soils are red in colour and have a mottled red and white subsoil.

This difference in colour between the red and black soils appears to be associated with the state in which the iron exists in the soil. The black concretons which appear to give the dark colour to the black soils are relatively high in iron. In the red soils, iron appears to exist in the free state and many of the particles in the fine sand fractions are stained dark red or yellowish brown with a coating of some oxide of iron. This iron dissolves in concentrated hydrochloric acid leaving white, opaque particles.

There seems to be no evidence to support the theory that the dark colour of the black soils is due to the high lime status of the humus, since black subsoils are met with which are almost free of organic matter. Black particles which are found in the fine sand fractions, yield iron to the solution when treated with concentrated hydrocholoric acid in the cold and become white and opaque.

(b) *Mechanical Composition.*

The more weathered soils, as would be expected, contain a somewhat higher percentage of the clay fraction.

In all the soils examined the clay content increases with depth indicating a mechanical eluviation.

2. CHEMICAL CHANGES.

(a) *Lime Status.*

All the surface soils examined have contained free calcium carbonate and have been alkaline in reaction. It would appear, however, that the calcium carbonate in the red soils, in the red sands and in the Valley soils examined, has been added since these soils were brought under cultivation. This is indicated by the fact that the subsoils in these cases contain little, if any free carbonate and possess a slight exchange acidity. In addition, marling appears to have been practised on these soils when slave or cheap labour was available. In all probability, then, these soils had become acid and base unsaturated under the original forest conditions and the development of these soils was due to the soil acidity which existed. The present alkaline conditions are due to applications of lime which have been made since these soils came under cultivation and, if this is so, further development is unlikely to take place.

The subsoils of the black soils which have been examined, contain as much or more free carbonate than the surface soils, and it would appear that these soils were never acid even under the original forest conditions existing when the island was discovered.

(b) *Composition of Clay Fractions.*

The clay fractions of the black soils have a silica-alumina ratio of about 4.6 which decreases to about 3.2 in the intermediate black and to about 2.5 in the red soils. It is thus evident that in the weathering processes, silica has been leached out of these soils. The profile examinations which have been made do not show any great variation in the composition of the clay fractions with depth. In some cases there is an indication of a decrease in the silica-alumina ratio with depth and this may be associated with the mechanical eluviation of the finer clay particles.

(c) *Composition of Fine Sand Fractions.*

The composition of the fine sand fractions of the soils examined show similar graded differences between the various soil types. The mean figures obtained have given a silica-alumina ratio of about 13 for the red, 25 for the intermediate black and 50 for the black. The silica content of these fine sand fractions varies from about 60% in the red soils up to 80% in the black. These figures indicate that the fine sand fractions have lost a considerable amount of silica as a result of the weathering processes which have taken place.

The profile examinations which have been made indicate that there is an increase in the iron content, a decrease in the alumina content and, in most cases, an increase in the silica content of these fine sand fractions with depth.

The fine sand fractions of the Carrington Valley soil show a big increase in the iron and a decrease in the silica content with depth.

(*d*) *Saturation Capacities.*

The saturation capacities, determined by the Kelly & Chapman method, show similar graded differences between the various soil types. By this method, the red soils have a saturation capacity of about 27 mgm. E. per 100 gram soil, which increases to about 37 mgm. E. in the intermediate black and to about 50 mgm. E. in the black soils.

Other methods of determining the saturation capacity were tried out and, although giving different figures for the same soils, they showed the same relative differences between the various soil types.

These figures show that, as silica is leached from the soil, the base absorbing capacity decreases; this agrees with the findings of Mattson (23).

(*e*) *Availability of Phosphate.*

The decrease in the silica-alumina ratio between the black and the red soils is associated with a decrease in the solubility of the phosphoric acid in water and dilute acids. The mean total phosphoric acid for the various soil types is very much the same, so that the decrease in availability as determined by chemical methods is most probably due to the fact that in the red soils the phosphate is partly or wholly in combination with free sesquioxides and in a more difficultly soluble condition.

Manurial trials which have been carried out on sugar cane, however, show that there is no response to phosphate manuring on any of the coral limestone soils although many of the red soils yield no water soluble phosphoric acid. Analyses of cane growing on these soils (24) also show the presence of comparatively large amounts of phosphate in the juice and in the entire sugar cane. The ordinary methods of determining available phosphate in the soil are therefore not suitable for detecting whether sugar-cane growing on these coral limestone soils will respond to phosphatic manuring.

3. FIELD BEHAVIOUR.

The respective field behaviour of the red and black coral limestone soils must be noted in any comparison of these soil types. It must first be stated that all the coral limestone soils are relatively easy to work in the field and would be classified as free working loams. The mechanical analyses show that the clay content of these soils varies from 50—70% and their good field behaviour must therefore be due to the composition of the mineral colloidal matter and to the fact that it is saturated with calcium.

The red soils behave in the field as if they were less colloidal than the black. They dry out more quickly under drought conditions and are more easily worked after rain. In view of the somewhat higher clay and organic matter content of the red soils, it is evident that this difference is due to a difference in structure of the mineral colloidal matter and is doubtless associated with the lower silica-sesquioxide ratio of the clay fraction.

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